Institute for European Environmental Policy

CLIMATE CHANGE AND THE RURAL ENVIRONMENT

IN A EUROPEAN CONTEXT:

IMPLICATIONS FOR LAND USE AND LAND USE POLICY

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ACRONYMS

BAP	Biodiversity Action Plan
CAP	Common Agricultural Policy
CHP	Combined heat and power
EAFRD	European Agricultural Fund for Rural Development
ECCP	European Climate Change Programme
ETBE	Ethyl Tertiary Butyl Ether
ETS	Emission Trading Scheme
FAME	Fatty Acid Methyl Esters
GHG	Greenhouse gases
HNV	High Nature Value
IPCC	Intergovernmental Panel on Climate Change
RMPs	Recommended management practices
RME	Rapeseed oil methyl ester
SRES	Special Report on Emission Scenarios
SOC	Soil organic carbon
SRC	Short rotation coppice

EXECUTIVE SUMMARY

Climate change is high on the political agenda, and has infiltrated the public consciousness as one of the most pressing environmental issues of our times. Whilst there is broad consensus over the scientific basis and causes of climate change (IPCC 4th Assessment Report, 2007), there is greater uncertainty over the impacts on land use and the natural environment due to the existence of feedback mechanisms and the influence of broad political, economic and demographic drivers. Climate change is likely to alter the comparative advantages between nation states, with water availability increasingly dictating the competitiveness and sustainability of land use sectors. Nation states will also vary in their capacity to mitigate the effects of climate change, whether these mitigation activities are technological or land use based. Strategies which seem appropriate at the present time, such as the use of food crops in the production of biogas and liquid biofuels, may be less so in the future in the context of an expanding population and an increasing demand for food. Politicians and policy makers will be faced with decisions over the use of land for food or fuel production, which will be informed by the price and availability of oil, agricultural commodities, and concerns over food access and security. In short, the unfolding political economy of climate change is difficult to anticipate.

Climate change adaptation and abatement is a global challenge. The effectiveness and sustainability of adaptation and mitigation strategies in any one nation or groups of nation states is highly dependent on those pursued elsewhere, and there is much scope for the impacts of climate change to be displaced, leading to an inequitable distribution of environmental and social costs and benefits. As such, the governance of climate change is both a global and a local issue. This paper, however, focuses on climate change and the rural environment in a European context. The logic behind this geographical circumscription is that many of the regulatory and economic drivers of climate change and its response unfurl at a European level, and the European Union provides a forum for political decision-making and leadership.

This paper examines the implications of projected changes in climate for Europe's rural environment through the lens of agriculture and forestry, the largest occupiers of the rural territory and the land uses with which much of Europe's biodiversity is intimately associated. It explores the potential contribution of these sectors to climate change abatement, which in turn, confers significant implications for the nature and pattern of rural land use in the future. It concludes with a discussion on the extent to which land use policy should intervene in the climate challenge and considers the implications for a reformed Common Agricultural Policy (CAP) post-2013.

Projected Trends in Climate Change

Europe's climate is changing, influenced by increased atmospheric concentrations of the three main greenhouse gases, carbon dioxide, methane and nitrous oxide. Along with the combustion of fossil fuels, land use change is a primary source of anthropogenic emissions of greenhouse gases. Whilst agriculture is a significant contributor of GHG emissions, contributing nine per cent of the greenhouse gas emissions of the EU-25 in 2005, its emissions are declining, with further decreases expected.

IPCC climate change scenarios for the European continent up to 2080 indicate widespread warming, with the greatest rises in temperature expected in southern and north eastern Europe. This will be accompanied by an increase in the frequency and intensity of heat waves, with greater risks of summer drought. Annual precipitation rates are expected to show a distinct spatial pattern, with increases and decreases expected in northern and southern Europe, respectively.

Potential Impacts

Rising concentrations of carbon dioxide, increasing temperatures and changes in precipitation will influence the productivity of the agriculture and forestry sectors, as well as impacting on soil quality and structure, and the distribution and proliferation of pests and diseases. These and other factors will interact in complex ways leading to a geographical variation in the magnitude of impacts. In general terms, yields of crops such as wheat, barley and rye, grown in northern Europe may increase in the short term, but this yield increase may be overridden in the longer term by factors such as more frequent flooding events. Conversely, farming systems in southern Europe will be most vulnerable to climate change, with water availability the limiting factor to production, leading to possible land abandonment or increases in the extent and intensity of irrigation. The net primary productivity of forests is expected to show a similar spatial pattern, with increases expected in boreal regions and declines in central and southern Europe.

Adaptation

Even if mitigation measures begin to reduce the volume of greenhouse gas emissions, they will be insufficient to arrest changes in temperature and precipitation rates. As such, adaptation measures are increasingly forming part of the strategic policy response to climate change. Adaptations can be behavioural, technological or management based. Whilst many have the potential to maintain the productive capacity of the EU's agriculture and forestry sectors, they are seldom neutral in their biodiversity impact. Many would disrupt the relationships between species, their habitats and land management practices established over long periods of time and which underpin much of Europe's valued biodiversity. Irrigation is a key adaptation strategy which is being pursued in southern Europe although it confers significant negative biodiversity impacts. The success of adaptation is dependent on overcoming major economic, political, institutional and social barriers and the integration of these measures with other policy objectives.

Mitigation

Whilst Europe's agriculture and forestry sectors are significant emitters of greenhouse gases, land managers can also play an important role in reducing sources of emissions or enhancing the removal of greenhouse gases through sinks. This can be achieved through livestock management, managing land use change, nitrogen management, avoiding deforestation, forestry management, and appropriate afforestation. Soil carbon sequestration is also an attractive mitigation measure and along with the preservation and reflooding of peatlands, provides ancillary environmental benefits.

Bioenergy

Agriculture and forestry have the potential to produce significant volumes of renewable energy and thus to displace the utilisation of fossil fuels. This energy can be in solid, gaseous or liquid form and is used in the generation of heat, electricity and liquid biofuels for transport. It is derived from conventional agricultural crops, dedicated bioenergy crops, agricultural waste and forestry residues.

In spite of the rhetoric, the use of first generation biofuels is not an environmental panacea. The input of fossil fuel energy during crop production and the conversion process is often high, there is a significant cost involved in abating carbon dioxide, coupled with the potential for large scale habitat destruction through the conversion of land both in Europe and in a global context. In combination, the environmental costs involved raise questions over the wisdom of a rapid upscaling in biofuel use to meet the recent Commission target agreed at the European Spring Council meeting, emphasising the imperative for policy, regulatory and market levers to steer the growth in biofuels in a sustainable direction.

In comparison, the production of electricity and/or heat from woody biomass and the combustion of biogas is relatively efficient and has high greenhouse gas savings as long as biogas is generated largely from agricultural waste, rather than conventional food crops such as maize. With the advent of second generation biofuels which are expected to be commercially available in the next 20 years, abatement costs should decrease and GHG savings should improve.

Even in the absence of a strong policy steer to incentivise the production of bioenergy crops, European energy policy, market forces and the anticipated end of arable set-aside are likely to drive an expansion in the area and intensity of cereal production for bioenergy feedstocks over the next decade. Early trends bear witness to this 'cerealisation' of the European countryside, with concomitant adverse environmental affects.

Implications for the CAP

A new set of policy drivers is emerging in rural Europe. Energy and climate goals are infiltrating a domain that has previously been dominated by food production and latterly sustainability concerns. These are likely to have implications for the future direction of the CAP, which has the capacity to influence land use decisions on a European scale, and raises questions about the relevance of current CAP objectives, the policy machinery required and the budget available for the sector in the longer term. Attention will need to paid as to whether this is an appropriate instrument to stimulate climate change mitigation or to deliver adaptation measures, and the extent to which pursuing such a trajectory compromises the policy's role in mitigating market failure in relation to the maintenance of High Nature Value farming and other environmental and landscape goods. Increased policy coordination is required, together with a strategic vision for the respective roles of food and energy production in Europe and the consequences for land use and the environment at a European as well as at the local scale.

1 INTRODUCTION

Climatic, pedologic and atmospheric conditions exert a profound effect on Europe's rural environment - its species, habitats, ecosystems and natural resources[1]. They are the basis for Europe's different biogeographical zones, which are stratified according to gradients in temperature, water availability and soil types, generating a vast range of habitat niches and supporting a wide array of species (Opdam and Wascher, 2004; Metzger *et al.,* 2005). Much of Europe's natural vegetation has been lost through conversion to agriculture and forestry, however, the range, distribution and net primary productivity of these anthropogenically manipulated systems is sensitive to, and constrained by, temperature, precipitation levels, atmospheric concentrations of carbon dioxide and nitrogen levels in the soil. This paper examines the implications of projected changes in climate for Europe's rural environment through the lens of agriculture and forestry, the largest occupiers of the rural territory and the land uses with which much of Europe's biodiversity is intimately associated (Beaufoy *et al.,* 1994; Bignal and McCracken, 1996; EEA, 2005; Reidsma *et al*., 2006). It explores the potential contribution of these sectors to climate change abatement, which in turn, confers significant implications for the nature and pattern of rural land use in the future. It concludes with a discussion on the extent to which land use policy should intervene in the climate challenge and considers the implications for a reformed Common Agricultural Policy (CAP) post-2013.

2 PROJECTED TRENDS IN CLIMATE IN EUROPE

In line with global trends, the climate in Europe is changing, broadly manifest in rising annual temperatures and changes in precipitation rates. The Intergovernmental Panel on Climate Change (IPCC) states that the observed widespread warming of the atmosphere and ocean, combined with ice mass loss over the last 50 years, means that it is extremely likely, greater than 90 per cent probability, that these changes cannot be attributed to natural variations in climate alone. Instead, they are due to the influence of increased greenhouse gas (GHG) concentrations in the atmosphere (IPCC, 2007). The three most important greenhouse gases are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), and the increases in their current concentrations are believed to have exceeded their natural range[2]. Methane and nitrous oxide are significantly more potent than carbon dioxide: every tonne of CH_4 and N_2O has the global warming potential of 21 and 296 times that of CO_2, respectively (New Scientist, 2006). The primary sources of anthropogenic emissions of CO_2 are fossil fuel combustion and cement production, and land use change, including deforestation and biomass burning, soil cultivation and the conversion from natural to agricultural ecosystems (Lal, 2004).

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[1] This paper focuses on the implications of climate change for the ecological and natural resource aspects of the rural environment, rather than for its social dimension.

[2] The global atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) in 2005 have been compared to pre-industrial values in 1750. CO_2 increased from 280 ppm to 379 ppm; CH_4 from 715 ppb to 1774 ppb and N_2O from 270 ppb to 319 ppb. The concentration of each gas in 2005 significantly exceeds the natural range observed over the last 650,000 years as determined from ice cores (IPCC, 2007).

As a land use sector, agriculture contributes to climate change, accounting for nine per cent of the GHG emissions of the EU-25 in 2005 (ECCP, 2006), a share which is significantly larger than its contribution to GVA, for example[3]. In addition, the conversion of forest to agricultural use led to the emission of 70 million tonnes of CO_2 equivalent in 2005 (EEA, 2007). The main gases emitted from agricultural activities are N_2O from soils and fertiliser use, and CH_4 from livestock digestion processes and manure management. GHG emissions from agriculture are declining, however, falling by 14 per cent between 1990 and 2003, with further decreases projected up to 2010. In part, these declines can be attributed to the implementation of environmental policies such as the Nitrates Directive (91/676/EEC) which poses tighter regulations on the use of fertiliser, to the unfurling effects of recent reforms of the CAP, manifest in a decline in livestock numbers, and to improved nitrogen management (ECCP, 2006; EEA, 2006).

The IPCC has developed scenarios to make projections for changes to the global climate to 2100[4], with a similar exercise conducted for the European continent[5]. Although there is variation in the exact outcomes of different scenario models, there is a consensus over the direction and extent of broad climate trends. All simulations show warming across the whole of the European continent and in all seasons (Kundewicz *et al.,* 2001). Annual surface temperatures in Europe are projected to rise at a rate of between 0.1 and 0.4^{o}C per decade (EEA, 2005a). The greatest warming is expected to occur over southern Europe, in countries such as Spain, Italy, Greece, and northeast Europe, in Finland and western Russia. The smallest increases will occur over the Atlantic coastline. Seasonal patterns indicate that in winter, the continental interior of eastern Europe will warm more rapidly, between 0.15 and 0.6^{o}C per decade. In summer, the predicted pattern of warming follows a pronounced south - north gradient, with southern Europe warming at a rate of between 0.2 and 0.6^{o}C per decade, and northern Europe warming between 0.08 and 0.3^{o}C per decade. The frequency and intensity of heat waves is predicted to increase throughout Europe, resulting in a greater risk of summer drought particularly in central and southern Europe.

The simulations indicate that there will be widespread increases in annual precipitation of between one and two per cent per decade in northern Europe, while decreases are expected across southern Europe up to a maximum of one per cent per decade. Smaller or ambiguous changes are expected in central European countries such as France, Germany and Hungary. This variation in participation rates will be

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[3] In 2005, 1.9% gross value added (GVA) of the EU-25 was produced by agriculture, hunting, forestry and fisheries (Eurostat). A disaggregated figure for agriculture is not provided.

[4] The UN IPCC developed climate change scenarios (known as the IPCC SRES – special report on emission scenarios) to project the effects of different greenhouse gas concentrations by 2100, based on extensive literature assessment, six alternative modelling approaches, and an 'open process' that solicited worldwide participation and feedback. The scenarios encompass the main demographic, economic, technological and land use drivers of GHG emissions in the future and assume no implementation of specific climate driven policy measures (IPCC, 2001).

[5] The ACACIA project and IPCC developed climate change scenarios for the European continent based on the SRES scenarios. The baseline period selected was 1961-1990 and changes in mean climate were calculated for the 2020s, the 2050s and the 2080s (Kundewicz *et al.,* 2001).

further differentiated according to season. Most of Europe will be wetter in the winter season, with the exception of the Balkans and Turkey. In the summer, northern Europe is predicted to have up to two per cent more rainfall per decade, whereas southern Europe is predicted to have a five per cent reduction in summer rain per decade.

2.1 The Potential Impacts of Climate Change on Agriculture

All agricultural systems across Europe are likely to be affected, at least to some extent, by the projected changes in climate in the coming decades (see Annex 1 for a review of the potential effects of climate change on selected arable, permanent crop and livestock systems). This is because rising concentrations of CO_2, increasing temperatures and changes in precipitation effect productivity, the quality and structure of the soil, and the abundance and distribution of pests and diseases. The complex interaction of these factors means that the impact of climate change on agriculture is subject to many uncertainties. However, potential impacts need to be anticipated to develop adaptation strategies and plan mitigation measures to ensure the continuing viability of the sector and to maintain and protect the environmental public goods associated with agriculture.

Climate change may have some positive effects on agricultural production in some regions over the coming decades. In the short term, a rising concentration of CO_2 can stimulate photosynthesis, leading to increases in biomass production in C3[6] crops such as wheat, barley, rye, potato and rice (EEA, 2004). The response is much smaller in C4 crops such as maize, although rising temperatures may enhance the productivity of these crops. Higher levels of CO_2 also reduce stomatal aperture and density on the leaves of both C3 and C4 plants which causes a reduction in transpiration and a concomitant increase in the efficiency of a plant's use of water (Olesen and Bindi, 2002). These benefits will be particularly pronounced in northern Europe, where higher temperatures coupled with increases in precipitation will serve to prolong growing periods, increase crop yields, decrease the risk of damage by freezing, allow cultivation of new crop species or render new land available for farming (Ecologic, 2007). As climate change advances, however, its negative impacts, such as more frequent winter floods, are likely to outweigh these benefits (EEA, 2004; IPCC, 2007).

Farming systems in southern Europe will be most vulnerable to climate change due to rising temperatures coupled with decreases in both summer and winter rainfall in areas already experiencing water scarcity (IPCC, 2007a). Furthermore, drought conditions alter the structure of agricultural soils, rendering the soil 'strong' and impenetrable to roots, further exacerbating the effects of drought (Whalley *et al.*, 2006). Responses to water scarcity may take a number of contrasting courses, with significant implications for biodiversity. On the one hand, arid conditions may render

[6] Plants can be divided into two categories based on the process by which they assimilate CO_2. In the first step of photosynthesis, C3 plants convert the carbon into a three carbon molecule, whereas C4 plants produce a four carbon molecule. C3 plants are more responsive to CO_2 levels, photosynthesising at a faster rate under increased CO_2 concentrations, whereas increased CO_2 has little effect on the rate at which C4 plants photosynthesise (Gillis, 1993).

agricultural production unsustainable, leading to the progressive marginalisation of the land and possible abandonment (DLG, 2004). On the other, the extent and intensity of irrigation may increase as farmers attempt to keep farming intensively in these areas. Even at the present time, southern Europe has the highest demand for water to irrigate crops such as cotton and fruit (IEEP, 2004; Ecologic, 2007) with increases in the irrigable area in France, Greece and Spain of approximately 30% observed between 1990 and 2000. Under drier conditions, more water will be required per unit area, and peak irrigation demands are expected to rise due to heat waves of increasing severity (Oleson and Bindi, 2002). Significant losses in biodiversity have been documented on account of dam building and the conversion of extensive farmland to irrigated fields (EEA, 2005b). In Spain, for example, the habitats of birds associated with cereal steppes have been lost to irrigation (Heath and Evans, 2000).

Changes in climate may encourage the proliferation of agricultural pests and diseases (Kundewicz *et al.*, 2001). Warmer climates provide more favourable conditions for insect pests by enabling them to complete a greater number of reproductive cycles. Warmer winter temperatures may also allow pests, such as aphids, to overwinter in areas where they are currently limited by the cold, thus causing a more extensive and earlier infestation during the following crop season (Olesen and Bindi, 2002). Higher concentrations of CO_2 may stimulate growth and the water use efficiency of weeds, thus altering weed-crop competitive interactions. The efficacy and duration of pesticide control is also affected by environmental conditions, such as temperature, precipitation, wind and air humidity. This may lead to an increase in pesticide use with associated negative environmental effects.

2.2 The Potential Impacts of Climate Change on Forests and Forestry

Forestry is also likely to be greatly affected in both positive and negative ways by the projected changes in the European climate in the coming decades. The net primary productivity of forests in boreal regions is expected to rise due to increased temperatures, CO_2 concentrations and levels of nitrogen deposition, however, in central and southern Europe, limited water will have the reverse effect and cause declines in regional productivity (Maracchi *et al.,* 2005).

Under a warmer climate, an extension to the northern range limits of most native tree species is expected. The actual rate of northward extension of the forest limit and of individual species is highly uncertain, however, because it depends not only on the rate of climate change, but also on associated rates of seed dispersal, the existence of anthropogenic barriers, species composition, the age of the trees, and the degree of fragmentation of the landscape (IPCC, 1997).

In mountain regions, certain species and communities could disappear completely because the upward displacement of species living close to the upper reaches of mountains will be constrained by the lack of any suitable habitat (IPCC, 1997). Early evidence of this may be seen in the southern slopes of the Pyrenees where the mountain pine is undergoing serious decline (Resco de Dios, 2007). A biome shift has recently been documented in northern Spain where *Fagus sylvatica*, European beech, is being replaced by *Quercus ilex*, holm oak, as *Quercus ilex* extends beyond the former upper limit of its range with the onset of milder weather conditions (Penuelas and Boada, 2003).

In large areas of west and central Europe, temperature increases could cause the replacement of natural conifers with more competitive deciduous trees such as *Fagus sylvatica* or *Quercus petraea*, sessile oak. Similarly, increases in winter temperature could encourage the survival of exotic species which may out compete native European species that are adapted to colder conditions. Adverse climatic conditions that weaken trees, such as a lack of water, will increase the risk of damage from pests and pathogens (Resco de Dios, 2007). Such losses are likely to be greatest for trees on the edges of their natural range. Climate change may be implicated in the increasing incidence of declines in the population of holm oak due to *Phytophthora cinnamomi* (Resco de Dios, 2007). Dutch elm disease and Hypoxylon canker attacks caused by fungi which favour high temperatures and dry conditions are likely to become more prevalent in southern Europe.

The impacts of climate change on Europe's land use sector are expected to vary in magnitude and to differ through space. The following section examines the adaptation strategies which could be pursued to preserve the functioning, viability and integrity of agricultural and forestry systems, and to minimise any adverse effects.

3 ADAPTATION MEASURES

Until recently, much of the research and policy response to climate change has focused on mitigation and fossil fuel substitution measures to reduce greenhouse gas emissions and to sequester carbon. However, with the adoption in June 2007 of the European Commission's green paper on 'Adaptation to Climate Change' this is set to change (European Commission, 2007). The paper recognises that even if mitigation measures begin to take effect and slow the increase in GHG emissions, climate change is inexorable. Indeed, model experiments show that if all greenhouse gases were held constant at year 2000 levels, a further warming trend would occur in the next two decades at a rate of about 0.1^{o}C per decade (IPCC, 2007). Actions to cope with a changing climate are thus presented as an indispensable complement to mitigation, rather than as an alternative. There are no explicit measures for agriculture and forestry detailed in the green paper, although they have been discussed in the Impacts and Adaptation Working Group of the second European Climate Change Programme (ECCP II) charged with exploring options to improve Europe's resilience to climate change impacts (ECCP, 2005).

Adaptation measures for the agricultural sector can be divided into options for the short and long term, depending on the magnitude of the change required.

3.1.1 Agricultural Adaptations in the Shorter Term

Water Conservation

Expanding the area under irrigation and increases in the intensity of water use is likely to be the main adaptation strategy in southern Europe, with evidence that this is already underway. However, it carries adverse consequences for the natural environment. Increased rates of water abstraction have led to lowered water tables and river flows, the disappearance of wetlands, damage to terrestrial and aquatic habitats upstream and the salinisation and contamination of groundwater (Baldock *et al.*, 2000). Further negative impacts arise from a higher use of agricultural inputs to increase agricultural returns which in turn, may affect a range of species, including farmland birds and aquatic organisms (EEA, 2005b).

Since climate change will increase water stress, especially in southern Europe, methods of adapting to low water availability will become increasingly important. Irrigation management can improve the efficiency of water use by making the timing and volume of water distribution more precise. Conservation tillage, the practice of leaving some of the previous season's crop residues on the soil surface, may protect the soil from wind and water erosion and retain moisture by reducing evaporation and increasing the infiltration of rainwater into the soil. This practice is not suitable, however, in large parts of Europe where fields are small and sloping, because it requires heavy machinery. Trees could be planted in the upper reaches of river catchments and peatlands restored to render them more capable of retaining water. Furthermore, small scale water conservation measures could be implemented, for example, collecting water from farm buildings for use on the farm and constructing on-farm reservoirs to supply water to the farm.

Changes in Planting Dates and Cultivars

For spring crops, climate warming will allow earlier planting or sowing, thus lengthening the growing season. This could increase the yields of long season cultivars if soil moisture is adequate. In southern states, short season cultivars that are planted earlier are more likely to reach maturity in advance of the arrival of extreme high summer temperatures, thus avoiding injury from heat and water stress (Maracchi *et al.,* 2005). Winter cereals have to pass through a specific growth stage before the onset of winter to ensure winter survival which may lead to later sowings in northern Europe (Kundewicz *et al.,* 2001).

Changes in External Inputs

Rising concentrations of atmospheric CO_2 will result in increased nitrogen uptake by crops, and this increase in demand may necessitate larger fertiliser applications. Adaptations could include growing nitrogen using leguminous crops and animal feeds, for example, roots, cereals, legume rich leys, in rotation (Kundewicz *et al.,* 2001). Atmospheric warming is also likely to lead to increases in pests, weeds and diseases, prompting additional herbicide and pesticide use. This could pose environmental problems in the absence of integrated pest management systems (Olesen and Bindi, 2002).

Changes in Animal Housing Systems

Higher temperatures in northern Europe may reduce the need for winter housing of livestock, although where there are rises in winter rainfall, more housing may be needed to reduce the level of poaching and risk of diffuse pollution. In those areas with a warm climate, housing could be adapted to a warmer climate, for example, by installing sprinklers in livestock buildings or in feedlots (Abildrup and Gylling, 2001).

Alternatively, additional shade could be provided for livestock through the restoration of hedges and planting of trees, which are beneficial for biodiversity.

3.1.2 Adaptations in the Longer Term

Changes in Land Use

The response of different crops to changes in climate will vary and as a result, changes in land use and the substitution of crops for those best adapted to the prevailing conditions may be one possible adaptation strategy. Crops could be substituted for those that are less dependent on irrigation, or that can cope better with heat and dry conditions, for example, deep rooted crops, such as Lucerne. In central Europe, optimal land use may involve increasing the area of winter wheat, maize and vegetables and decreasing the area of spring wheat, barley and potato which will be less suited to increased temperatures and lower water availability (Olesen and Bindi, 2002). As high levels of water abstraction becomes unsustainable in arid areas, agricultural production may become less viable and ultimately abandoned. The rice sector in Spain, Portugal and Greece is particularly vulnerable (Agra Europe, 2007). Water availability is likely to become the major driver of future land use, precipitating land use changes.

Crop Breeding

Biotechnology offers the possibility of developing varieties of crops and trees that are more tolerant to heat and water stress and different diseases and insect pests (see, for example, Laporte *et al.*, 2002).

In theory, many of the impacts on the productive capacity of the agriculture and forestry sectors can be addressed. However, some of the more extreme measures would precipitate changes to land use and structural changes, both in terms of the landscape and farming systems. All of these carry implications for the natural environment as they would disrupt the relationships between farmland species, their habitats and land management practices established over long periods of time (Bignal and McCracken, 1996). Crop substitution would, for example, remove habitats for certain farmland species and potentially create habitats for others, thus changing the balance of species found in a particular area. Many of these species are already under threat, as habitat loss is further exacerbated by climate change. These effects have been demonstrated in the MONARCH project, for example, which showed that for those British BAP species modelled, a majority are likely to experience changes in the range and / or extent of their suitable habitats by 2020, 2050 and 2080 (see Walmsely *et al*., 2007). Under such circumstances, there will be a need to develop and maintain an interlinked network of habitat and ecological networks to ensure species survival, as is the goal of the Natura 2000 network (Opdam and Wascher, 2004; Chambers and Ball, 2007). Some of the adaptation measures will constitute a significant challenge for public policy as they will require significant investment and will cause shifts in the comparative advantages of regions and, thus, in their competitiveness.

3.2 Forest Adaptation Measures

In productive forests, existing stands may be replaced with species that are better adapted to changing climatic conditions to overcome problems of decreased timber production, expected in southern and parts of central Europe. Tree species sensitive to drought could be substituted with more drought tolerant tree species, although new species must be introduced with caution so as not to be potentially invasive and threaten the native species that remain. The emphasis should be on using native species of conservation value. To protect against increasing pathogen and pest numbers, the genetic composition of forests could be broadened with increased species diversity in forest stands. More dynamic forest management practices could be employed, for example, using wider spacings and earlier and more intensive thinning regimes to reduce vulnerability to wind storms whilst also improving the availability of water in the soil (EEA, 2005a). In areas where windblow is an increasing problem, planting of trees at unsuitable sites could be avoided, for example, spruce in coastal Scotland. Changes to thinning regimes could also be used to take account of the altered competitive relationships between individuals of different tree species due to changes in climate. Reforestation could be carried out at higher altitudes adjacent to natural stands to facilitate tree migrations (Kellomaki and Leinonen, 2005; Resco de Dios *et al*., 2007), although consideration should be given to the habitats replaced. In particular, it will be important to ensure that alpine habitats are not lost due to afforestation.

These measures should not, however, be applied unilaterally in all forests. For example, in unproductive or forests with high natural value, the introduction of exotic, more drought tolerant, species would not be appropriate, as they would have negative impacts on the nature values of the forest and its ability to provide hydrological goods and services. Continuous cover forestry with natural regeneration, which takes advantage of natural forest dynamics, is an approach with many advantages in maintaining biodiversity and wood production (Peterken, 1996). Continuous cover maintains a shaded micro climate on the forest floor, which is more likely to ensure the continuity of the present woodland flora and fauna (Defra, 2007). It may be possible to modify traditional systems to make them more resilient to climate change by, for example, retaining shading during coppicing using standard (full height) trees or leaving some stools uncoppiced. Careful planning would be necessary to provide for those species, such as dormice, which require a more open canopy and seasonal food sources from the shrub and herb layers (Defra, 2007).

Whilst in theory, the measures discussed offer solutions to moderate the adverse effects of changes in climate on both agriculture and forestry, little research has been conducted into the relative effectiveness, cost and efficiency of various approaches, or on the time if takes the system to adapt. Timeframes are particularly pertinent in a forestry context as the results of decisions about planting and species composition take several decades to come into effect. The success of adaptation measures is highly dependent on overcoming major economic, institutional, political, social and behavioural barriers (IPCC, 2007a) leading to a pressing need to align these measures with other policy objectives such as reducing flood risk and soil erosion, conserving biodiversity, and maintaining both the quality and quantity of water supplies.

4 MITIGATION MEASURES

Whilst the agriculture sector is a prime emitter of GHGs, there are various measures that can be taken to mitigate GHG emissions, to sequester GHGs from the atmosphere and to store them in terrestrial carbon sinks.

Climate change mitigation encompasses all activities which are designed to slow or reduce the total climate change effect. Specifically, mitigation is defined as an anthropogenic intervention to reduce the sources or enhance the removal of greenhouse gases through sinks (IPCC, 2002). The agriculture sector has the potential to carry out a range of mitigation activities. There is not the space in this paper to discuss all of these in detail but see Weiske and Michel, 2007 and Smith *et al*., 2007, for a comprehensive description and review of these measures. In brief, they include: manure/biosoil management, for example, a reduction in ammonia and methane emissions could be achieved by reducing the surface area of manure exposed to the air through regular washing or scraping of the floor in animal housing; methane emissions can be reduced from slurry based manure systems by increasing the manure storage temperature; livestock management, for example, modifying livestock feeding strategies such as adjusting the feed composition to decrease the amount of nitrogen excreted to reduce nitrous oxide emissions; land cover and land use change; agro-forestry; crop management; tillage/residue management; nutrient management; water management; grazing land management/pasture improvement; management of organic soils.

Forests are also important for mitigating GHG emissions since they contribute considerably to the terrestrial carbon sink. A number of measures could be used to increase the carbon sink of forests. Schelhaas *et al.* (2007) propose that the largest carbon effects are likely to be achieved by changes in management to increase current sinks such as increasing the rotation length, increasing the thinning share and shifting to continuous forest cover, however, more intensive thinnings could have negative biodiversity impacts. Avoiding deforestation also maintains the carbon sink and avoids the rapid emission of carbon dioxide when a forest is felled. Afforestation can increase the overall carbon sink, however new forest areas initially sequester carbon at a slow pace and so it would take a long time for any significant difference in the carbon sink to be achieved.

The remainder of this section focuses on soil carbon sequestration as a climate change mitigation strategy. This is because, with the exception of bioenergy, covered in the following section, a large proportion of the mitigation potential of agriculture arises from soil carbon sequestration (IPCC, 2007) and its application carries implications for future trends in land management and use.

4.1 Soil Carbon Sequestration

Soil carbon sequestration implies the removal of atmospheric CO_2 by plants and the storage of fixed carbon as soil organic matter. Under Article 3.3 of the Kyoto Protocol, which is mandatory, emissions and removals from afforestation, reforestation and deforestation since 1990 are counted towards the emissions targets of Annex 1 countries[7].

Article 3.4 makes provision for the optional inclusion of emissions and removals from additional land management activities relating to the improved management of forests, cropland and grazing land, land restoration and re-vegetations. Carbon sequestration has significant potential in the short to medium term to offset CO_2 emissions and yet the policy steer has been relatively weak in a European context where the focus has been on emissions reductions as the primary mechanism to mitigate climate change[8].

This reticence stems, in part, from a perception that carbon sequestration is a risky, and therefore perhaps unviable, mitigation strategy in the long term. Concern has been articulated with regard to uncertainty over the rates of accumulation, the permanence and measurement of carbon stocks (Lindner and Karjalainen, 2007), and the complexity of the interaction between indirect and natural factors which impact, in unpredictable ways, on the scale and direction of soil carbon fluxes (Smith, 2005). Specifically, the environmental lobby feared that a focus on sequestration may divert attention away from the pursuit of a net cut in industrial, domestic and other emissions - a more sustainable trajectory. Whilst these objections are rationally sound, the shortcomings of carbon sequestration as a climate mitigation strategy are tempered by the provision of substantial ancillary environmental and economic benefits, including an improvement in soil structure (see Soils Thematic Strategy, European Commission, 2006a), and reductions in flood risk via peatland restoration. These additional public benefits render it an important area of activity and policy intervention.

Soils can either be a source or a sink of carbon[9]. To maintain the role of soils as a net sink, the rates of depletion of carbon from the soil need to be minimised, and its absorption capacity, and thus its sequestration potential, maintained or enhanced. The global potential of soil organic carbon (SOC) sequestration has been estimated by Lal (2004) to be 0.9 +/- 0.8 Pg C/year, which equates to between one quarter and one third of the annual increase in atmospheric carbon levels, measured at a rate of 3.2 +/- 0.1 PgC/year. This figure for sequestration potential is widely quoted, however, the actual potential may be significantly lower[10]. Soil carbon content depends on the rate

[7] Those industrialised nations that signed up to the Kyoto Protocol.

[8] In contrast to the US, where the Bush administration and Congress, although not ratifying the Kyoto Protocol, have supported the use of agricultural soils to sequester carbon through domestic farm policies and have funded major research initiatives to support agricultural sequestration under the framework of the 2002 Climate Action Plan (Young *et al*., 2007).

[9] There is a broad consensus that the atmospheric concentration of carbon is increasing at a rate of 3.2 +/- 0.1 PgC/year based on figures from the 1990s. Of this, 6.3 +/- 1.3 PgC/year are from fossil fuel combustion and cement production, and 1.6 +/- 0.8 PgC/year are from land use change, including soil cultivation. A significant proportion is subsequently reabsorbed by sinks including the oceans, 2.3 +/- 0.8 PgC/year, and the territorial sink, 2.3 +/- 1.3 PgC/year (Lal, 2004; Smith, 2005).

[10] Other estimates differ widely, suggesting that the realistically achievable potential may be significantly lower (Smith, 2004). Freibauer *et al*., (2004), for example, have estimated that agricultural soils in the EU-15 have the potential to sequester up to 16 – 19 Mt C / year during the first

of addition of carbon from plant growth - net primary productivity - against the rate of removal of carbon through the decomposition of organic matter, leaching and other soil processes such as disturbance and erosion. As such, the sink potential is highest when there are high crop yields, minimal levels of soil disturbance and low rates of decomposition of soil organic matter. Low rates of decomposition tend to occur in those countries with low temperatures and wet conditions. Each of these factors, however, is sensitive to changes in land use, historic and present management, climatic conditions and other variables (Freibauer *et al*., 2004) so there is a wide variation in the sequestering potential of soils in different regions.

In addition to the variables mentioned above, there are a number of management options - recommended management practices (RMPs) - which increase the total organic carbon content of the soil, and thus the soil's sequestration potential. The most promising approaches are summarised below, although each carry implications for farm profitability and could be constrained by the availability of suitable land and other resources. All of the practices identified could be stimulated through policy intervention, within the existing framework of the European Agricultural Fund for Rural Development (EAFRD)[11] and its potential successor, and cross compliance, but would require a significant adjustment in the objectives that rural development measures seek to address.

Measures for increasing soil carbon inputs centre on enhancing net primary productivity, stimulated through judicious nutrient management and methods of livestock management. An adequate supply of nitrogen and other essential nutrients in the soil can enhance biomass production under elevated CO_2 concentrations, in turn enhancing the SOC pool. The amount of carbon in the soil can also be increased by the preferential use of animal manure, crop residues and sewage sludge, and the incorporation of cover crops in the rotation cycle. Measures to minimise the depletion of the SOC pool focus on reducing soil disturbance and include reduced or zero tillage systems on cropland[12] and the growth of perennial crops in the place of annuals.

The organic carbon content of the soil will be increased by the conversion of conventional agriculture to other land uses with high carbon inputs and low levels of disturbance, such as natural regeneration and permanent set aside (Guo and Gifford, 2002). Included in this suite of measures is the conversion of cropland to grassland or

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Kyoto commitment period (2008 – 2012), which is less than one fifth of the theoretical potential and equivalent to two per cent of European anthropogenic emissions. Smith *et al*., (2000) estimated that a realistic potential for carbon mitigation on UK agricultural soils is 10.4 Tg C/year, which is about 6.6 per cent of the UK's CO_2 emissions in 1990.

[11] The EAFRD was created as a single fund for rural development for the European Member States under European Commission Regulation 1698/2005 on support for rural development by the European Agricultural Fund for Rural Development (OJ L277/1 21.10.2005). This Regulation provides Member States with a framework for the targeting of support within rural development programmes running from 1 January 2007 to 31 December 2013.

[12] As organic matter contains nitrogen as well as carbon, increasing the soil organic carbon content also provides more substrate for nitrogen loss by leaching and N_2O emission. For practices that potentially increase denitrification (for example, no-till), these N_2O losses can be substantial and may have a significant impact on the overall GHG mitigation potential (Smith *et al*., 2001).

pastures, which is widely cited as the most effective carbon mitigation option (Schuman *et al*., 2002; Smith, 2004).

The maintenance or reflooding of peatlands is also an important carbon sequestration measure. This is because peatlands absorb significant volumes of carbon from the atmosphere and emit very little in turn due to the slow decomposition of peatland plants. In spite of the important role played by peatlands as a net carbon sink, there has been a dramatic decline in peatland cover across western Europe over the last century. For example, in the United Kingdom and Ireland over 90 per cent of raised bogs have been lost. More than 50 per cent of the original peatland resource remains in only six countries in the European continent, Russia, Latvia, Liechtenstein, Norway, Sweden and the Ukraine. (see http://www.peatlandsni.gov.uk/formation/euro.htm). Peat is threatened by drainage, burning, grazing and climate, all of which lead to releases of carbon. Drainage is associated with environmental degradation including increased flood risk.

Whilst it is desirable to encourage carbon sequestration activities, the carbon sequestration potential of the soil is not limitless, and even with proactive management, it does not have the capacity to absorb increasing volumes of carbon in perpetuity. A point is reached at which the sink strength is decreased to zero and there is no further uptake of carbon from the atmosphere, with the exception of peat bog which will continue to accumulate organic matter, and thus sequester carbon, indefinitely if in good condition. This is referred to as sink saturation (Watson *et al*., 2000). The time taken for sink saturation is highly variable, but for soils in a temperate location, such as Europe, the period to reach a new equilibrium after a land use change is around 100 years (Smith, 2005). Furthermore, the carbon sequestered in agricultural soils is not stored permanently, and the carbon sequestering activity needs to be maintained even after the sink is saturated. Indeed, if a land management or land use change is reversed or discontinued, the carbon which has been accumulated is lost at a rate more rapid than the one at which it was accumulated. As such, management regimes, once established, should not be revoked. On privately owned land, this carries significant implications for the 'freedom to farm' of future generations and, if it were to be effective, implies the setting up of a covenant which is binding on the current and subsequent landowners[13]. It is unlikely, therefore, that arrangements of this type will apply over large areas of land unless they are made a management condition of long term environmental set aside, or Ecological Priority Areas (Cooper *et al.,* 2007 in prep).

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[13] The Queen Elizabeth II National Trust in New Zealand has set up a system of open space covenants to protect natural features and habitats. These are legally binding protection agreements entered into between the Trust and landowners, and which are registered on the title of the land. The covenants are voluntary, but once in place, they are binding on the current, and all subsequent landowners (see www.nationaltrust.org.nz).

5 BIOENERGY FROM AGRICULTURE AND FORESTRY

Agriculture and forestry have the potential to produce significant volumes of renewable energy from biological sources and thus to displace the utilisation of fossil fuels. In theory, increases in the volume of bioenergy produced will reduce greenhouse gas emissions and thus contribute to meeting obligations under the Kyoto Protocol and wider climate change objectives.

In March 2007, the European Council approved the Commission's Energy Package, which will lead to the introduction of a mandatory target for renewable energy use of 20 per cent of the total energy mix. In addition, a minimum mandatory target for biofuel utilisation of 10 per cent of overall consumption of petrol and diesel in transport by 2020 was set[14]. To meet the 2020 targets, it is indicated that much of the growth in renewable energy would come from the increased use of bioenergy for the production of heat and electricity, as well as biofuels for transport. The 10 per cent biofuels target exceeds that which is technically possible through current levels of production of blended fuels. It is also unlikely that Europe has the capacity to supply its own needs, at least if much of the demand is supplied through first generation food crops, and imports of feedstocks are expected to rise in the future. It is thus important that the Community's policy is integrated with climate policy and is developed in a coherent way in order to provide solutions that lead to the greatest reductions in GHG emissions.

The following section identifies the crops and feedstocks involved in bioenergy production in Europe at present, and outlines the main bioenergy production chains. The GHG emission reduction potential of different production chains is considered alongside the relative costs in terms of the volume of CO_2 abated. Europe's bioenergy production capacity is discussed, assuming compliance with reasonable environmental standards. Finally, the land use implications of these trends in production and the associated impacts on biodiversity are examined.

5.1 Feedstocks and Bioenergy Production Chains

Solid, gaseous or liquid forms of energy can be produced from conventional agricultural crops capable of high biomass yields, for example, cereals and sugar beet; oilseed crops, such as oilseed rape, linseed, field mustard, hemp and sunflower; the organic residues and wastes from food crops, such as cereal straw and livestock waste; (Tuck *et al*., 2006); from the food industry and from industrial and household waste (EEA, 2006). The cultivation of high yielding, non food crops such as *Miscanthus*, short rotation coppice, (SRC) and *Eucalyptus,* dedicated to the generation of bioenergy has emerged as a more recent phenomenon. Each of these feedstocks can be fed into a range of bioenergy production chains to produce heat, electricity and

[14] These targets supersede, to a significant degree, those specified in the Biofuels Directive (2003/30/EC) which set indicative 'reference levels' for biofuel use in each Member State. Reference values for the targets were set at two per cent at the end of 2005, rising to 5.75 per cent by the end of 2010.

liquid transport biofuels (see Annex 2 for a more detailed description of bioenergy feedstocks and liquid biofuels). Some of the key production chains include:

- The production of electricity and/or heat from the combustion of woody biomass, such as the by products of forestry operations, including harvesting residues and sawdust, straw, short rotation coppice (SRC), *Miscanthus* and *Eucalyptus*.
- The production of electricity and/or heat from the combustion of biogas - primarily in the form of CH_4 - generated from the anaerobic digestion of agricultural residues such as livestock wastes, maize or grass silage.
- The production of biodiesel, or Fatty Acid Methyl Esters (FAME) - a first generation liquid biofuel[15] - through the esterification of vegetable oils from crops such as oil seed rape, linseed, field mustard, hemp and sunflower.
- The production of bioethanol or Ethyl Tertiary Butyl Ether (ETBE) - a first generation liquid biofuel - from the fermentation of plant biomass, specifically carbohydrates in the form of sugars, starch or cellulose sugar of conventional agricultural crops, such as cereals and sugar beet. This is a substitute for, or additive to petrol.
- The production of second generation liquid biofuels such as ethanol, Dimethyl Ether, Substitute Natural Gas or Fischer-Tropsch diesel through the, as yet mainly experimental, processes of gasification or enzyme treatment of agricultural by products such as straw, *Miscanthus* and SRC, which are not yet grown on a commercial scale, although the crop technology is well advanced.

5.2 Reductions in GHG Emissions

5.2.1 GHG Savings from Liquid Biofuels

In spite of the rhetoric, the use of first generation biofuels, is not a panacea for the reduction of GHG emissions. This is both because the input of fossil fuel energy during crop production and the conversion process is often high, and because the production of biofuel feedstocks results in the depletion of the terrestrial (biomass and soil) carbon sink and the release of N_2O from fertilised soils. Indeed, some commentators are beginning to question the legitimacy of including first generation biofuels under the 'green energy' banner given the small volume of GHG emissions reduced relative to their fossil fuel counterparts, and the potential for large scale habitat destruction caused through the conversion of land in both a European and global context[16]. In addition to the small GHG savings and volume of CO_2 emitted

[15] Liquid transport biofuels are often referred to as 'first' and 'second generation' biofuels. This distinction stems from differences in the feedstock, the conversion technology and their commercial viability at the present time, rather than a difference in the end product. Bioethanol, for example, can be derived from both first and second generation biofuel production chains.

[16] An increase in the production of bioenergy crops is likely to have profound implications for global biodiversity as tropical forests – 'biodiversity hotspots'; - are cleared on a large scale to make way for rapidly expanding monocultures of oil palm and soy. Friends of the Earth estimate that 87 per cent of the deforestation in Malaysia from 1985 to 2000 was caused by new palm oil plantations. In Indonesia, the amount of land devoted to palm oil has increased by 188 per cent in the last eight years (Rosenthal,

during the generation of biofuels, there is also a significant cost involved in abating CO_2. Coupled with issues of land availability, the optimal use of land for food, bioenergy and industrial products, the potential to generate heat, electricity and liquid transport biofuels from household and industrial waste, and the distribution of environmental costs, raises questions over the sagacity of such a rapid upscaling in biofuel use and on the role of policy, regulatory and market levers in steering this growth in a sustainable direction (LowCVP, 2007).

As biofuels are composed mainly of organic carbon compounds, they emit CO_2 in significant quantities when they are burnt as fuel. However, because growing feedstocks absorb CO_2 from the atmosphere, the release of CO_2 emitted during biofuel combustion does not contribute to new carbon emissions since the emissions are already part of the fixed carbon cycle. That said, biofuels are not 'carbon neutral' because additional GHG emissions are emitted during cultivation and processing.

According to the expanding literature, there is considerable variation in the GHG savings of conventionally produced biofuels, ranging from a negative saving to one that exceeds 100 per cent (Dufey, 2006), although savings of between 40 and 80 per cent are corroborated by a number of sources. Estimates vary in part because of differences in methodological approach and assumptions about energy efficiency. However, the extent of savings do depend on different combinations of feedstocks and cultivation practices, the production process, and whether or not by products are used in energy production. The GHG balance is particularly uncertain because N_2O emissions from agriculture are rarely incorporated into calculations (although see Mortimer *et al*., 2003).

Conventional production of biodiesel from rape seed and sunflower oil, as practiced in Europe, reduces GHG emissions by approximately 50 per cent compared to fossil diesel (Schroder and Weiske, 2006; TNO *et al*., 2006). Bioethanol, however, shows wider variations, although the savings are generally more modest. Estimates for wheat based bioethanol point to reductions ranging from 19 – 47 per cent, and for sugar beet based bioethanol from 35 – 53 per cent. Calculations from a recent study based on German data suggest that these figures are lower, estimating that ethanol from wheat reduces GHG emissions by as little as eight per cent per driven kilometre compared to conventional petrol use[17] (Schroder and Weiske, 2006).

2007). A Dutch study estimated that the draining of peatland in Indonesia, primarily for the production of palm oil for biodiesel, released 600 million tonnes of carbon into the atmosphere and that the fires to clear the ground for plantation contributed an additional 1,400 million tonnes annually. The total, 2000 million tonnes, is equivalent to eight per cent of all global emissions caused annually by burning fossil fuels (Rosenthal, 2007). The conversion of tropical peatlands is not only a concern in terms of carbon dioxide emissions, but peatland soils are also important water retention areas, slowly releasing water during the dry season and helping to prevent floods and drought (Wetlands International, 2007). They also provide habitat for threatened bird and mammal species such as the Sumatran Ground-cuckoo and the Orangutan (BirdLife International, 2006).

[17] This compares to estimates for bioethanol derived from sugarcane produced in Brazil which shows GHG savings of 80 per cent relative to fossil fuels. This is because in Brazil, sugarcane has a high growth rate, a high sugar content, and the waste 'bagasse' - what is left after the extraction of the sugar - is used to process heat (TNO *et al*., 2006). On the basis of GHG savings alone, it is preferable to import Brazilian bioethanol to Europe, rather than to produce it domestically from wheat and sugar beet. The situation, however, is more complex with additional environmental costs involved.

Given that first generation biofuels result in comparatively low reductions in GHG, there is a growing imperative to invest in their second generation counterparts. Initial estimates of GHG savings from second generation biofuels are speculative, but typically suggest a 70 – 90 per cent reduction compared to conventional gasoline (IEA, 2004; JNCC, 2007).

5.2.2 CO_2 Abatement Costs of Liquid Biofuels

One of the biggest barriers to the large scale expansion of biofuel production is the higher economic costs of first generation biofuels compared to conventional fuels. As with GHG savings, cost is influenced by a number of factors including domestic crop prices, feedstock yields, the country of provenance, and the cost and efficiency of various stages in the transformation process (von Lampe, 2006). At a global scale, sugar cane for bioethanol, and oil palm trees for biodiesel, grown in tropical and sub-tropical climates, are the most efficient feedstocks. They are considerably cheaper and produce more biofuel per hectare compared to corn produced in Europe, for example (Laney, 2006). Of the conventional biofuels currently available, ethanol from Brazilian sugar cane is the most competitive, with CO_2 savings at abatement costs of €20 - 40 per tonne. There is, however, a strong dependence between the cost of carbon equivalent savings and oil prices; as the oil price rises, biofuel options become more attractive. A study for the OECD has calculated that for national biofuel production in the US, EU and Canada to become profitable without subsidies, oil prices would have to be considerably higher than at present, ranging from €35 - 155 per barrel (von Lampe, 2006).

It is expected that costs will fall with the advent of second generation biofuels. It has been estimated that lignocellulosic ethanol could produce CO_2 reductions at abatement costs of approximately €160 per tonne, becoming cheaper than ethanol from most conventional crops. In the medium term, owing in part to lower feedstock costs, production of ethanol from hydrolysis could fall below €80 per tonne of CO_2 abated (TNO *et al*., 2006).

Given the high costs involved, coupled with relatively low GHG savings, the Commission's statement that 'biofuels are the only available large scale substitute for petrol and diesel in transport' (European Commission, 2006) seems misguided when applied to first generation biofuels, but much more justifiable when second generation biofuels are available commercially.

5.2.3 GHG Savings from Woody Biomass

The use of woody biomass for combined heat and power production has high efficiency and GHG savings. Woody biomass sources include woody perennial crops, such as SRC and *Miscanthus,* and forestry and straw residues, collected following harvesting. Taking into account the ecological constraints of residue extraction, Schelhaas *et al*., (2007) estimate a potential of GHG emissions avoided equal to the equivalent of 13.5TgC/year in the EU-25 from forestry residues. Another potential source of biomass is through increased fellings. The same study found that increasing the felling level every five years yields an equivalent of 3.8 TgC/year of avoided emissions. These two measures in combination offer the potential to avoid an equivalent of 17.3 Tg C/year of emissions, although there would be a concurrent depletion of the carbon sink of the forest at a rate of 15.2 Tg C/year, thus neutralising, to a considerable extent, the savings in carbon emissions. The increased use of woody biomass, can, for example, have biodiversity consequences, as the presence of deadwood in the forest is important for biodiversity.

5.2.4 GHG Savings from Biogas

Biogas production is a technology that can be applied at the farm scale and has a favourable GHG emissions footprint compared to fossil fuels (JRC, 2007). This is supported by calculations of savings of GHG emissions in a German context which indicate that biogas production is the most attractive bioenergy option as it offers high GHG savings at a low reduction cost provided that the heat produced in the process can be used productively (Schröder and Weiske, 2006).

Biogas is therefore an attractive option in theory, however it is currently largely produced using maize, which has little associated biodiversity, is intensively produced and has a high water demand. Indeed the area under maize in Germany, where the majority of biogas is currently produced, increased from 372,000 hectares in 1996 to 462,000 hectares in 2004 whilst Germany's production of maize has doubled in the past decade: 2,446,000 tonnes in 1994 to 4,200,000 tonnes in 2004 (Agra Europe, 2007). This indicates that biogas production may encourage both the more intensive production of maize and an expansion in its area.

5.3 Land Use Implications

In 2005, an estimated 3.6 million hectares of agricultural land in the EU-25 were allocated to the production of feedstocks for the generation of heat, electricity and liquid biofuels[18]. A majority of the land was used for the production of oil seed crops for biodiesel (83 per cent); with a further 11 per cent for wheat and sugar beet, for bioethanol; four per cent for maize for biogas production; and two per cent for short rotation forestry.

Europe is a major producer of biodiesel, accounting for 90 per cent of the total production worldwide (JNCC, 2007). Its production increased more than 20 fold between 1994 and 2005, and in 2005, it accounted for 3.1 per cent of total renewable energy production (EEA, 2006). This is driven, in part, by the widespread use of diesel in Europe, whereas it is less prevalent in other markets, such as the US. In 2006, approximately 17 million tonnes of rapeseed were produced in the EU, of which a large majority was grown in five Member States: Germany, France, the UK, Poland and the Czech Republic (Ollier, 2006). Of this, between 60 and 70 per cent

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[18] Support for farmers growing energy crops is provided under the EAFRD Regulation 1698/2005 (2007-2013). Establishment grants of up to 50 per cent are available for permanent crops and the Energy Crop Supplement of €45 per hectare is available in all Member States of the EU-27. The maximum area of land eligible for support under this scheme is two million hectares which excludes all set aside land. Silcock and Lovegrove (2007) estimate that six million hectares of set aside land is currently under production of non food crops, including those for bioenergy and industrial use.

served as a feedstock to provide rapeseed oil methyl ester (RME) for liquid biofuels. Reflecting an ever increasing demand for biodiesel, production is projected to increase to 20 million tonnes in 2010 – 2015.

Approximately 69 Mtoe of the EU's total primary energy consumption is currently met from biomass sources (EEA, 2006), just over a quarter of that which would be required to meet the EU's mandatory target for renewable energy use of 20 per cent of the total energy mix. It has been calculated that for this target to be met, approximately 250 million tonnes of oil equivalent (Mtoe) will be required from primary biomass potential, depending on assumptions about total energy consumption, increases in other renewable energy sources and the end use of the biomass (EEA, 2006), although it is unlikely that this will all come from domestic production.

Various projections have been made of the land use implications of a growth in the production of bioenergy within the European Union. In the Biofuels Progress Report, (European Commission, 2006), the Commission calculate the area of arable land that would be required in 2020, given a range of assumptions about the biofuel share of total road fuel demand. It is estimated that in 2020, the total area of arable land required for biofuel production will be between 7.6 million and 18.3 million hectares, equivalent to approximately 8 per cent and 19 per cent respectively of total arable land in 2005 if we assume a biofuel share of total road fuel demand of seven and 14 per cent. Under the latter scenario, of the 18.3 million hectares of arable land required, they estimate that 7.5 million hectares would be arable land formerly used in the production of food, seven million hectares would be former set aside land, and four million hectares would be derived from an expansion of the area under arable production.

Another study has investigated the land potential for biomass production in individual Member States with the results suggesting a concentration in the cultivation of bioenergy crops in certain areas of Europe (Thran *et al*., 2005). The land potential for biomass production in France, Germany, Denmark, Ireland, the Baltic Member States and Hungary is high due to the availability of large areas of high yielding agricultural land. In Poland, significant areas of fallow land are expected to be available and Spain has a high land potential due to a declining agricultural population, although the cultivation of bioenergy crops in Spain may be significantly threatened by climate change in the future[19]. Italy, the Netherlands, Belgium, Luxembourg and Greece have a low land potential for biomass production. In the UK, land potential for further bioenergy production is also low, based on assumptions about the rate of population growth.

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[19] Tuck *et al*., (2006) assessed the impact of climate change on the potential future distribution of bioenergy crops under each of the IPCC SRES scenarios. In line with predicted trends in conventional crops, the potential distribution of temperate oilseeds, cereals, starch crops and solid biofuels is predicted to increase in northern Europe by the 2080s, due to increasing temperatures, and decrease in southern Europe (Spain, Portugal, southern France, Italy and Greece) due to shortages in the availability of water. All models indicate that most of southern Europe will be vulnerable to climate change and the growth, in these regions, of all temperate oilseeds, starch crops, cereals and soil biofuel crops is expected to be seriously impaired.

These shifts in agricultural production and land use are reasonably fluid, however, as the feedstocks for bioenergy are expected to change over time. In 2010, 40 per cent of the bioenergy from agriculture in Europe is projected to come from conventional biofuels produced from oil seed rape and cereal crops. Over time, demand for these crops is expected to decline as they are replaced by more efficient feedstocks such as SRC and *Miscanthus* (EEA, 2006).

5.4 Biodiversity Impacts

The impact on biodiversity of the cultivation of bioenergy crops will depend, in part, on their pattern of distribution within landscapes. The biodiversity impact is likely to be more favourable if bioenergy crops are dispersed over a sizeable area and a significant number of farms, forming a mixed cropping pattern. In contrast, the concentration of one type of bioenergy crop in large blocks, forming dense areas of monoculture, will lead to a simplification in the structural diversity of the landscape, with considerable negative impacts on biodiversity (Baudry *et al.,* 2000; McCracken and Klockenbring, 2007).

Biodiversity impacts will also depend, to a large extent, on the quality of the land use or habitat that the bioenergy crops replace. If more marginal, extensively managed land is replaced by bioenergy crops, overall biodiversity effects will be negative. The ploughing up or intensification of extensive grassland would generally lead to a loss in biodiversity value and a release of soil carbon (Schelhaas *et al*., 2007a). Conversely, where bioenergy crops contribute to land use heterogeneity, for example, by introducing an arable system into an area dominated by grassland, biodiversity benefits may occur (McCracken and Klockenbring, 2007).

If, in the short term, the bioenergy targets stimulate an increased production of crops, such as wheat and oil seed rape for first generation biofuels, negative impacts on biodiversity are likely to result. Owing to the questionable economics of conventionally produced biofuels, there is strong pressure for high yields and thus these crops are likely to be produced in an intensive manner. Nutrient input is generally high for wheat, maize, oilseed rape, and sugar beet, in particular, has a relatively high impact on soil structure as it requires the use of heavy machinery during harvesting (EEA, 2006).

It is difficult to assess the biodiversity impacts of growing woody perennial crops, such as SRC and *Miscanthus*, since commercial scale plantations are not yet widespread in Europe. In comparison with conventional arable crops, however, they generally have less impact on soil structure and compaction, since after establishment no further ploughing is required and they use nutrients economically, resulting in low fertiliser requirements (Schelhaas *et al*., 2007a).

There is some evidence that large scale SRC plantations can provide benefits for some taxonomic groups, for example, bird species typical of rank herbaceous vegetation, scrub and young woodland, as well as butterflies and flowering plants (Anderson and Fergusson, 2006). The bird community associated with SRC would be expected to change in response to the cycle of growth and subsequent harvest of the crop. Densities of some bird species, such as tits, thrushes and warblers, characteristic of woody/scrub habitats may increase, while bird species preferring open habitat, such as skylarks and wagtails would decrease as the crop became established (Anderson *et al.,* 2004). It is unlikely that SRC will confer benefits on farmland bird species of biodiversity concern as they are typically more closely associated with open farmland habitats. On the other hand, SRC crops provide an important opportunity to reduce the problem of nutrient run off when planted along buffer zones adjacent to water bodies (IEEP, 2004).

Literature is scarce on the links between growing perennial grasses for bioenergy and biodiversity since this is still in the early stages of commercial development. Hope and Johnson (2003) suggest that given the structure of the crops – tall, high density grasses – they will provide poor habitat for arable plants, birds and large mammals, although they may benefit ground dwelling invertebrates and small vertebrates.

6 THE CONTRIBUTION OF THE COMMON AGRICULTURAL POLICY TO THE CLIMATE CHALLENGE

A new set of policy drivers is apparent in rural Europe. The combination of energy and climate policy objectives to meet targets for 2020, many of which are determined at a European level, are influencing a domain where agricultural supply and, more recently, sustainability concerns have been dominant. Climate science, new approaches to both adaptation and mitigation objectives, and the growing focus on bioenergy supply will have implications for farming, forestry and other sectors of the rural economy. Sustainability and environmental objectives are being reexamined and, in some cases, contested. The relationship between rural and urban areas is being viewed through a new prism. The extent to which the countryside will need to take responsibility both for new energy supplies and carbon sequestration in response to emissions from predominantly urban sources is at present unclear.

The European Union does not have a land use policy. It does possess, however, a well established agricultural policy with the capacity to influence land use decisions on a European scale. As energy and agricultural policies operate increasingly in the same domain, new questions about the relevance of the current CAP objectives, the policy machinery required and the budget available for the sector in the longer term arise. These will be more prominent in the debate over policy beyond 2013. The potential for unencumbered thinking about the future of policy relating to agriculture, climate and land use in Europe is increasingly apparent.

At the present time, climate change has entered the lexicon of the CAP but has made relatively little impact on the policy measures it contains. The principal focus has been on incentives for growing energy crops, where the objectives have been wider than the mitigation of greenhouse gas emissions or climate change, reflecting a concern to diversify farm incomes, for example. There has been little attention given to mitigation from carbon sequestration or delivering adaptation as priorities for agricultural policy. In the second Pillar of the CAP, concerned broadly with rural development, there are no dedicated measures responding to the climate challenge. There is, on the other hand, a clear instruction to the Member States in the Strategic Guidelines that their rural development programmes should address Community priorities, one of which is climate change. In this sense, the process of absorbing a new climate dimension into the CAP is in its infancy.

By contrast, the combination of climate and energy policy is coalescing into a force that could drive agricultural production and longer term structures in the countryside, either operating alongside more traditional rural policies, or even overwhelming them. As energy policy incorporates an expanding number of targets for renewable energy supplies in the EU, it is set to generate increased market demand for a specific set of agricultural commodities. The biofuel and bioenergy targets for 2020, agreed in March 2007, are a case in point. Even if a substantial proportion of demand is met through imports to the EU, production of oilseed rape and crops for ethanol production seems set to rise rapidly, and in the short term, national measures to meet the EU targets will play an important role. This is likely to affect crop prices and land use to a considerable degree and reinforce the case for abandoning mandatory arable set aside as a measure within the CAP. European energy policy, accompanied by national measures of varying degrees of vigour, could effectively incentivise and support aspects of arable production over a sustained period of years.

At the same time, there is a need to consider Europe's global footprint and to ensure we do not export or encourage unsustainable practices in pursuit of European climate goals. There will need to be a balance between domestic and global responsibilities. One aspect of this will be the debate over the sustainability of bioenergy and carbon sequestration technologies. Standards for bioenergy crops, whether voluntary or mandatory, will be part of this equation.

If demand and price levels for arable crops moved high enough there could be consequences well beyond the likely termination of set aside which itself will have negative consequences for biodiversity, water quality and carbon sequestration. For example, the case for continued direct payments for arable farms could be much weakened if farms were more profitable and land prices correspondingly higher. Livestock farms seem likely to fare less well from renewable energy targets and may be incentivised to convert more grassland to arable. At present, cross compliance stipulations should inhibit any large net loss of grassland to arable, but the influence exerted by the policy may decline over time if Pillar One payments continue to shrink. Even within the current cross compliance rules, some loss of permanent grassland, which is valuable from a biodiversity perspective, can occur. There seem likely to be tensions between bioenergy and carbon sequestration objectives on grassland as well as concerns about biodiversity if the arable area expands. Active intervention will be required to protect biodiversity and water quality objectives in a potentially more productivist arable landscape

In short, the bioenergy issue will give a new prominence to climate and energy policy in the agricultural world, although there is uncertainty about the likely scale of demand and of European production. A new level of coordination between these policies and the CAP will be required, together with a more strategic vision of the respective roles of food and energy production in Europe and the consequences for land use and the environment.

In more concrete policy terms, there are questions about how far intervention is needed to encourage a response to the climate challenge from the rural sector –

covering agriculture, forestry, the natural environment, recreation and tourism, housing, transport and other activities. It will be important to keep the focus on the public interest as a new set of lobbies and private interests emerge. Market failure, such as the lack of incentives to maintain High Nature Value (HNV) farmland will remain a key basis for intervention.

Perhaps the most fundamental challenge is to reduce greenhouse gas emissions and increase energy efficiency. Since many operations are small scale it is not obvious that the emissions trading system (ETS) would suit either agriculture or forestry, although this approach is being considered in relation to farming in New Zealand, for example. A mixture of advice and information, appropriate technical standards, less generous tax arrangements for agricultural fuels, and incentives for developing and applying technical measures beyond good practice could all play a role. The rural development pillar of the CAP offers one channel for providing incentives, especially for less wealthy Member States.

There are many possible mitigation options to pursue. Some of the most interesting are those which offer multiple benefits, above and beyond reducing emissions. For example, there are opportunities both to reduce nitrous oxide emissions and at the same time to reduce water pollution by improved management of slurry and other livestock wastes. The re-flooding of oxidised peat soils in selected locations could contribute to soil conservation, climate and biodiversity goals. A cross cutting approach to policy based on a revised conception of rural priorities could both feed through existing policies, such as Pillar Two of the CAP and the Nitrates Directive, and inspire new initiatives. It would sharpen the focus on land use issues and priorities in Europe without requiring a significant shift in responsibilities from the local and national level.

The current focus on providing incentives to grow conventional agricultural crops for bioenergy purposes is more difficult to defend. While there may be political pressure to increase incentives for growing energy crops to stimulate supply, this does not appear good value for money in the light of the buoyant market and limited increase in carbon efficiency achieved by substituting first generation biofuels for fossil fuels. Energy policy already provides strong incentives for bioenergy production in many Member States and will continue to do so throughout the Union as EU binding targets for 2020 stimulate further measures at national level. As the technology makes second generation biofuels more feasible, the case for incentivising appropriate crop production on a limited scale to encourage new technology may become stronger, but such goals are located in the domain of energy rather than agricultural policy.

Much less attention has been paid to the need to manage environmental stress arising from the impacts of climate change. This includes pressures on biodiversity, the need to facilitate the migration of species, changes in traditional landscapes, flood management and reduction in rural water supply. Investment will be required to mitigate negative impacts and manage adaptation in the rural environment. These pressures could be increased by inappropriate large scale production of bioenergy crops and any intensification of food production. It is important to establish environmental safeguards to prevent damage from biofuels and encourage sustainable production. Investment in the environment will need to come from both national and

EU sources. Here too, there is a potential role for Pillar Two of the CAP and key questions are raised about the availability of sufficient funds.

From this perspective, the response to climate change in the rural environment does not need to be a remodelling of the CAP. A series of specific and targeted measures, informed by a land use and environmental perspective and supported by an adequate budget, would respond to new and sometimes unpredictable requirements. Certain of these measures will fall within conventional agricultural policy, many outside it. Links between farming, energy and environmental policy perspectives need to be strengthened and institutional relationships adjusted accordingly.

This is not an argument for a static CAP. As it adapts it needs to move further beyond its roots in agricultural markets and the support of farm incomes. The logic of a more carbon centric rural policy is to have a greater focus on resource management in the countryside both in agriculture and forestry. For example, commodity production can be viewed from a new perspective, reflecting the role of annual crops, woodier crops such as short rotation coppice and forestry in an overall carbon budget. Soil management becomes a more important issue than previously and the capacity to monitor and even steer land use changes becomes a European, as well as local, concern.

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ANNEX 1 PROJECTED IMPACTS OF CLIMATE CHANGE ON ARABLE, PERMANENT CROP AND LIVESTOCK SYSTEMS

Sector	Specific Crop	Effect of Increased Temperature	Effect of Increased CO_2	Impact on Geographic Distribution
Cereals	Wheat	Temperature increase will shorten length of growing season, reducing yields (since determinate species[20]).	Large yield increase due to C3 species outweighs negative temperature effect. Predict increase of 9 - 35 per cent of wheat yield across Europe by 2050 (Maracchi *et al.,* 2005).	Expansion of cereal cultivation northwards (Harrison *et al.,* 1995). Largest increases in yield expected in southern Europe, especially northern Spain, southern France, Italy and Greece (EEA, 2004). The drier conditions and increasing temperatures in the southern Mediterranean, such as southern Portugal and southern Spain, may lead to lower wheat yields and the need for new varieties and cultivation methods to maintain cereal production.
	Maize	Increased temperatures, particularly in the southern regions will decrease yield due to shorting growing season.	Small effect due to C4 species.	Increases in yield for northern areas, decreases in southern areas.
Seed Crops		Temperature increase will shorten growing periods of determinate species.		The cropping areas of cooler season seed crops, such as pea, faba bean and oil seed rape, may expand northwards into Fenno-Scandanavia, leading to an increased productivity of seed crops but reductions in yield elsewhere (Maracchi *et al.,* 2005). Similarly, a northward expansion of warmer season seed crops such as soybean and sunflower is expected.
Vegetables		Increased temperature will reduce the duration of crop growth and hence yield in determinate species, such as onion. An extended growing season will increase the duration of growth of indeterminate species, such as sugar beet, if enough water is available.	Root and tuber crops likely to show a large response due to underground capacity to store carbon and apoplastic mechanisms of phloem loading (Maracchi *et al.,* 2005).	For field grown vegetables, increasing temperatures may expand production northwards.

[20] Determinate plant species do not continue to grow indefinitely at the apex, but terminate in a flower. Their time to maturity depends on temperature and day length, and increased temperatures will shorten the length of the growing season, reducing yields.

Sector	Specific Crop	Effect of Increased Temperature	Effect of Increased CO_2	Impact on Geographic Distribution
		For cool season vegetable crops such as cauliflower, large temperature increases may decrease production in southern Europe during the summer.		
Perennial Crops	Grapevine	This woody perennial responds readily to high temperatures.	May strongly stimulate yields without causing negative repercussions on grape or wine quality.	Increased temperatures and CO_2 will expand the potential growing area northwards and eastwards. However, yield variability will increase, implying economic risk.
	Indeterminate energy crops, e.g. *Miscanthus*	Favoured by conditions that extend the growing season and increase the light or water use efficiencies. For willow production in the UK, a temperature increase of $3^{o}C$ may increase yields by up to 40% (Olesen and Bindi, 2002).	Increases water use efficiency.	
Livestock Systems	For livestock systems, climate change may have both positive and negative impacts. Increased temperatures and the likelihood of extreme weather events may increase the need for animal housing; prolonged dry weather may increase the need to supplement forage with bought-in feed, silage or forage, potentially increasing feed costs; changes in global feed markets may affect costs; increased variability in grazing regimes due to wetter soil in autumn/winter; increases in disease – e.g. spread of Bluetongue into Northern Europe (Purse *et al.,* 2005). Climate change could herald a shift into feedlot systems where temperature can be controlled and waste more easily used to generate energy – i.e. the collection of manure for use in biogas production (for example, Farming Futures, 2007). However this would have animal welfare implications as well as effecting biodiversity since it would reduce grazing and may impact adversely on HNV farming systems.			

ANNEX 2 BIOENERGY FEEDSTOCKS AND LIQUID BIOFUELS

7.1 Woody Biomass

Woody biomass can be burnt to generate electricity and/or heat, and in the production of second generation biofuels. The most common woody biomass feedstocks are by products of forestry activities, such as saw dust and residues from tree harvesting, short rotation coppice (SRC), *Miscanthus* and straw. Forestry by products require processing to reduce their moisture content and increase their density before conversion into fuel chips (RCEP, 2004) which are then burnt in a solid biofuel boiler. The hot gases produced are used to heat water which is either used directly (in a heat only plant) to distribute the heat, or the hot water is evaporated to produce high pressure steam to drive an electrical generator in combined heat and power (CHP) plants. Utilising the heat in addition to the electrical power leads to a significant improvement in conversion efficiency.

The dispersed nature of supplies of forestry products, however, renders their use in the large scale production of energy unlikely. As such, the use of woody biomass for bioenergy production is better suited to small scale CHP or district heating applications, serving rural communities adjacent to forests, or forest industries such as sawmills, to provide heat and power for their manufacturing processes.

SRC consists of densely planted, high yielding varieties, typically either willow or poplar, harvested on a two to five year cycle, although generally every three years. Willow and poplar are woody, perennial crops, whose rootstock or stools remain in the ground after harvest with new shoots emerging the following spring. A plantation could be viable for up to 30 years before replanting is necessary, although this depends on the productivity of the stools (RCEP, 2004). Willow and poplar tend to be grown on less productive arable land or grassland and thrive on moisture retaining, well aerated clay or sandy loams (Silcock and Lovegrove, 2007). The high water requirements of willow can constrain its cultivation to areas where sufficient water for irrigation is available at reasonable cost and without unacceptable environmental damage (RCEP, 2004).

Miscanthus is a tall woody perennial rhizomatous grass which grows rapidly and is harvested on an annual basis. It is economical in its use of nutrients and has a good internal recycling system. Much of the nitrogen, phosphorus and potassium is translocated from the leaves and stems and stored in the unharvested rhizome and thus its annual fertiliser demands are said to be low (RCEP, 2004). *Miscanthus* is best suited to lowland sites with deep, moisture retentive soils (Silcock and Lovegrove, 2007).

7.2 Biogas

Anaerobic digestion of agricultural residues such as excrements, cereals, maize or grass silage can be used to produce biogas which is then combusted in heat or CHP units to produce electricity and heat. Biogas production is a technology that can be applied at farm scale. As it is derived from a fossil carbon free biomass waste product, and it abates emissions of methane, it has a favourable GHG emissions footprint compared to fossil fuels (JRC, 2007).

7.3 Liquid Biofuels

Liquid biofuels offer an alternative to oil based gasoline (petrol) and diesel. At present, these are principally bioethanol and biodiesel, with bioethanol dominating global production (JNCC, 2007). Liquid transport biofuels are referred to as 'first' and 'second generation' biofuels.

First generation biofuels are characterised by:

- A high dependence on food crops (e.g. sugar, cereals, maize for bioethanol and oil seed rape, and sunflower oil for biodiesel);
- The use of commercially proven processes of fermentation and transesterification;
- Processes that use only part of the plant feedstock with significant residue remaining;
- Processes that generate only modest savings in CO_2 emissions relative to fossil fuels.

Second generation biofuels are characterised by:

- The utilisation of a wide range of crop types, including energy crops such as willow, poplar and *Miscanthus*, and by products of arable farming such as straw;
- The use of new, as yet uncommercial, processes using hydrolysis, gasification and fermentation;
- Processes that use the entire crop biomass as such producing considerably more energy per hectare. They are more energy efficient and less demanding in their requirements for land;
- Processes that achieve a significant reduction in CO_2 emissions relative to fossil fuels.

Bioethanol

Ethanol is used as a gasoline (petrol) substitute directly, or as Ethyl Tertiary Betyl Ether (ETBE). The process of ethanol production deploys established techniques and is widespread throughout the world. The US and Brazil are the major producers globally, whilst in Europe, France, the UK, Spain and Germany dominate bioethanol production, most of which is generated from cereals (Schroder *et al.,* 2006).

On a volume for volume basis, ethanol contains less energy than gasoline, and one metric tonne (mt) of bioethanol contains the same amount of energy as 0.6 mt of fossil fuel equivalent (JNCC, 2007).

Biodiesel

Pure vegetable oils (consisting of fatty acids) can be used as transport fuel but they have a significantly higher viscosity than fossil fuel diesel which results in incomplete combustion in the engine and poor engine performance. True biodiesel involves processing of vegetable oils to create a more uniform product (fatty acid methyl esters FAME) suitable for use in high performance diesel engines (JNCC, 2007). The main producers in the EU include Germany, France and Italy and rape seed is the feedstock of virtually all of the European biodiesel produced at the present time (Dufey, 2006; JRC, 2007).